Sediment Transport and Strata Formation in the Adriatic Sea

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LONG-TERM GOALS

The long-term goal of this project is to develop quantitative models of sediment transport, resuspension, deposition and accumulation on the continental margin.

OBJECTIVES

The objectives of this research are 1) to characterize the structure of the river plumes and coastal currents in the western Adriatic Sea and their influence on sediment dispersal from Alpine and Apennine rivers; 2) to assess the relative contributions of Alpine and Apennine rivers to the clinoform development in the Adriatic, and to determine the delivery mechanism of these different sources; 3) to determine the mechanisms and rates of sediment resuspension and bottom-boundary-layer sediment transport in the western Adriatic; 4) to determine how bottom-boundary-layer processes influence the patterns of erosion and deposition in the western Adriatic.

APPROACH

WHOI contributed to the major field effort in the Adriatic, starting in the fall of 2002 and continuing to June 2003. The field effort included tripod and mooring deployments along the Adriatic margin (Fig. 1), large-scale hydrographic surveys at various times through the deployment period, and repeated hydrographic sections at selected locations. The tripod measurements included currents, water properties and suspended sediment. Bed elevation was monitored at selected sites using acoustic backscatter sensors (ABS). The combination of moored and shipboard measurements provided temporal and spatial resolution of the sediment dispersal system of the western Adriatic, extending from the mouth of the Po River to the Gargano peninsula and encompassing the Apennine river inputs as well as the Holocene clinoform deposit (Trincardi et al., 1996).

WORK COMPLETED

The major elements of the water-column observational program in the Adriatic started in the fall of 2002, and included the deployment of an array of tripods and moorings and the first of four regional hydrographic surveys (Fig. 1). Mooring turnarounds and two additional hydrographic surveys were conducted in February 2003. A final hydrographic survey and mooring recovery took place in late May, 2003. Fortuitously, the mooring deployment occurred just prior to one of the largest Po

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14. ABSTRACT
The objectives of this research are 1) to characterize the structure of the river plumes and coastal currents in the western Adriatic Sea and their influence on sediment dispersal from Alpine and Apennine rivers; 2) to assess the relative contributions of Alpine and Apennine rivers to the clinoform development in the Adriatic, and to determine the delivery mechanism of these different sources; 3) to determine the mechanisms and rates of sediment resuspension and bottom-boundary-layer sediment transport in the western Adriatic; 4) to determine how bottom-boundary-layer processes influence the patterns of erosion and deposition in the western Adriatic.

15. SUBJECT TERMS

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discharge events of the decade (peaking at 8,000 m^3/s; Fig. 2), which provided an ideal opportunity to quantify the influence of the coastal current on the dispersal system. The wind field, which is the other major forcing agent of the coastal current, is spatially complex in the Adriatic Sea because of the surrounding mountains and the occurrence of the Bora winds that are funneled through the mountain passes of Croatia during cold-air outbreaks in the winter. Winds were obtained from the Limited Area Model Italy (LAMI) model (7 km grid) simulation for the period of the measurements, providing an accurate rendering of the spatial and temporal variability of the wind field (Fig. 2, 2nd panel).

RESULTS

Near-surface currents measured near the Po and at varying distances downstream (Fig 2, 3rd panel) show the combined influence of winds and the freshwater inflow. The currents near the Po do not show any clear evidence of a coastal current, due apparently to the complex, near-field regime. However, at the Ravenna and Chienti transects (70 and 200 km south of the Po delta), a strong net southward transport is evident, modulated by wind-forced motion. Currents reach nearly 100 cm/s when the Coastal current first reaches each of these transects in early December, and similar velocities occur during short-lived wind bursts from the North. Near-surface salinities show the progression of the coastal current signal down the coast, with a 2-week lag between the drop in salinity at the Po and the frontal arrival at Ravenna, and another week before it arrives at the Chienti transect. The salinity signal is attenuated due to mixing as it propagates down the coast, but the drop of 18 psu at the Chienti line indicates that the buoyancy forcing is intense, even in the far-field. One of the distinctive features of the salinity signal is the abrupt increase that occurs during strong wind-bursts from the north (e.g., early January). Preliminary analysis indicates that the increased salinity occurs as a result of vertical mixing, which occurs in conjunction with strong downwelling (BORA condition).

The transverse structure of the coastal current was clearly revealed by the hydrographic surveys, which also captured the variability associated with changes in wind-forcing conditions. During moderate downwelling conditions (Fig. 3, left panels), the coastal current is 10-15 km wide, stratification is weak, and the low-salinity water contacts the bottom as deep as the 20-m isobath. Bottom stress results in resuspension throughout the coastal current, but most intense in the shallow water. During weak upwelling conditions (Fig. 3, right panels), the coastal current is advected offshore, becoming thin in the vertical and more stratified. Bottom stress is reduced, and suspended sediment concentrations are reduced. During strong upwelling conditions, wave-induced stresses become large, causing intense resuspension in the wave-boundary layer, but the strong stratification and weak along-shore flow in the bottom layer limit the vertical extent of sediment resuspension. These conditions may lead to hyperpycnal transport, as discussed below, but strong upwelling has little influence on the along-shore sediment flux (Fig. 4).

The temporal variations and depth dependence of the suspended sediment concentrations clearly show the dominance of downwelling conditions in contributing to the along-shore flux, based on estimates of near-bottom suspended sediment from echo amplitude of the ADCPs and ABS and velocities from the ADCP and ADVs. (Fig. 4). The periods of large flux all occur during downwelling events, and they coincide with periods of strong southward flow. Even the most intense upwelling winds produce only modest resuspension outside the wave boundary layer (e.g., the upwelling event around 17 November compared to a downwelling event on 26 January, Fig. 4).

There was a prolonged period of upwelling-favorable winds in late November, during much of the interval of Po freshwater inflow. These conditions would favor the local trapping of sediment in the

near-field, based on the above observations of the coastal current processes. The acoustic backscatter sensor (ABS) data at the WHOI tripod at 12-m depth revealed several periods in which fluid mud (concentrations > 10,000 mg/l) appeared in the wave boundary layer during November and early December Fig. 4). These high concentration events were due to resuspension by large surface waves with significant wave heights greater than 2-m and an easily remobilized bed due to the recent sediment input from the Po.

During the first of these events (Fig. 5), the bottom tripod was lowered approximately 20 cm (due to scour of the feet, not net deposition), which put the bottom ADV velocity sensor sampling volume 7 ±4 cm above the bottom (distance estimated from the bed return of the ABS data; uncertainty estimated from the tilting of the tripod as it settled and the horizontal distance between the ABS and the ADV). This puts the sampling volume of the ADV either just inside or within several cm of the top of the fluid mud layer, which was 5 to 10 cm thick. Velocity profiles from the ADVs and the ADCP show an offshore flow of 5 to 10 cm/s at 0.5 meters above bottom (mab) associated with these high concentration events. The flow persists in the offshore direction even when mean onshore currents are observed at 1 mab. When high concentration layers are not present, thin near-bed offshore flows are not observed and the velocity profile is a typical frictional boundary layer. This indicates that the high-concentration offshore flows are due to the excess density of the fluid mud and bottom slope (i.e. the mud is sliding downhill).

IMPACT/APPLICATIONS

The hydrographic and moored data clearly indicate the dominant influence of the Po in the freshwater anomaly of the coastal current, and thus in its mean southward transport. Based on the small size of the Apennine river basins relative to the Po, the buoyancy contributions of these systems is only of local significance, even in the most extreme floods. However, the sediment inputs of these systems may be significant, notwithstanding the recent reduction in sediment yield due to changes in land use and flood control (Dal Cin et al., 1993).

The analysis of this data set and the comparison with numerical model results will provide considerable information about the mechanisms of sediment dispersal and bed evolution at regional scales. The Adriatic is an excellent model system for many river-influenced continental margin systems. The results of this analysis will provide a significant improvement in our ability to assess and predict environmental conditions in coastal environments and their impact on optical and acoustic sensing systems.

TRANSITIONS

RELATED PROJECTS

A proposal was submitted to ONR's Office of Coastal Geosciences in July 2003, entitled, "EuroStrataform Analysis". This project would combine the data analysis with detailed examination of the numerical simulations of the Adriatic.

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PUBLICATIONS

PATENTS

HONORS/AWARDS/PRIZES

FIGURES

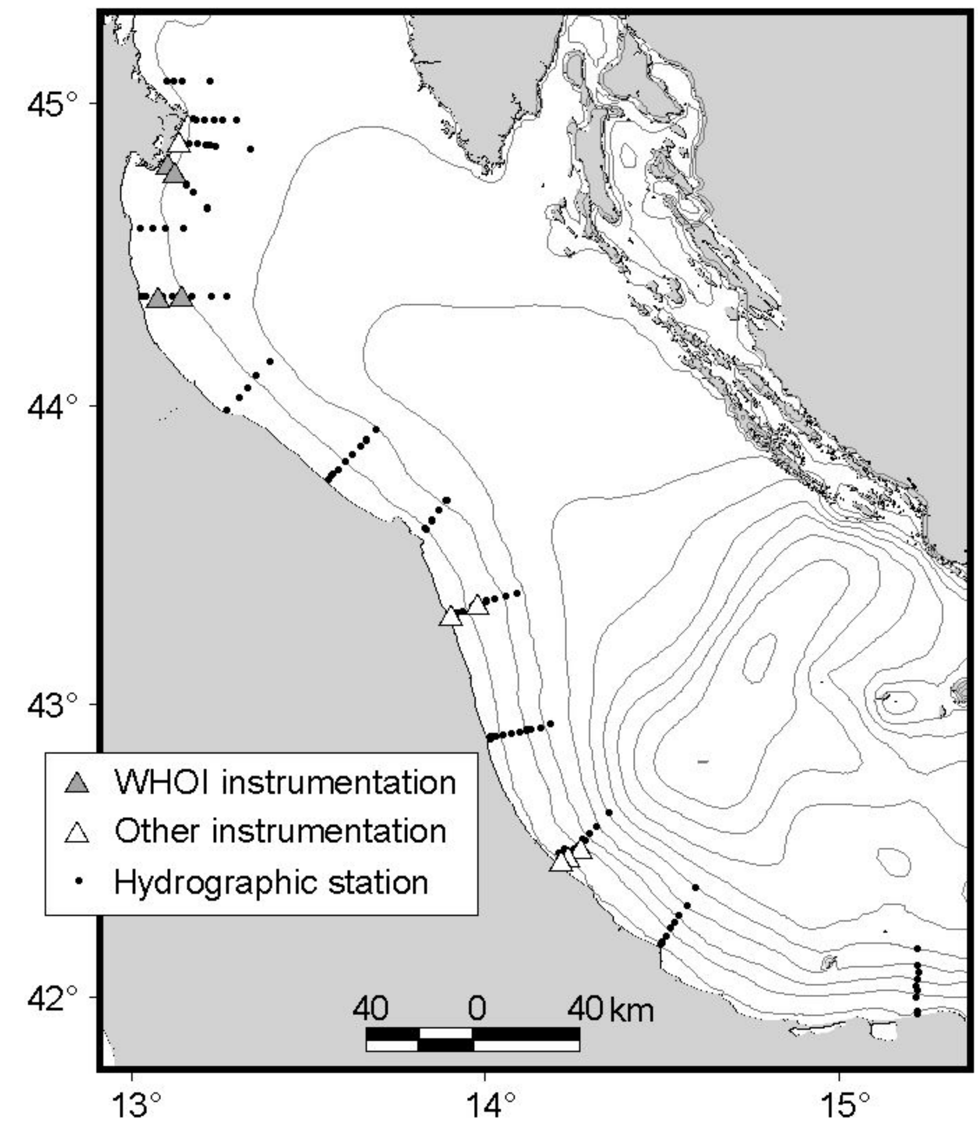

Fig. 1 Tripod location (triangle) and hydrographic station location (dot) for the capital PASTA water column and boundary layer study. Contour interval is 20m.

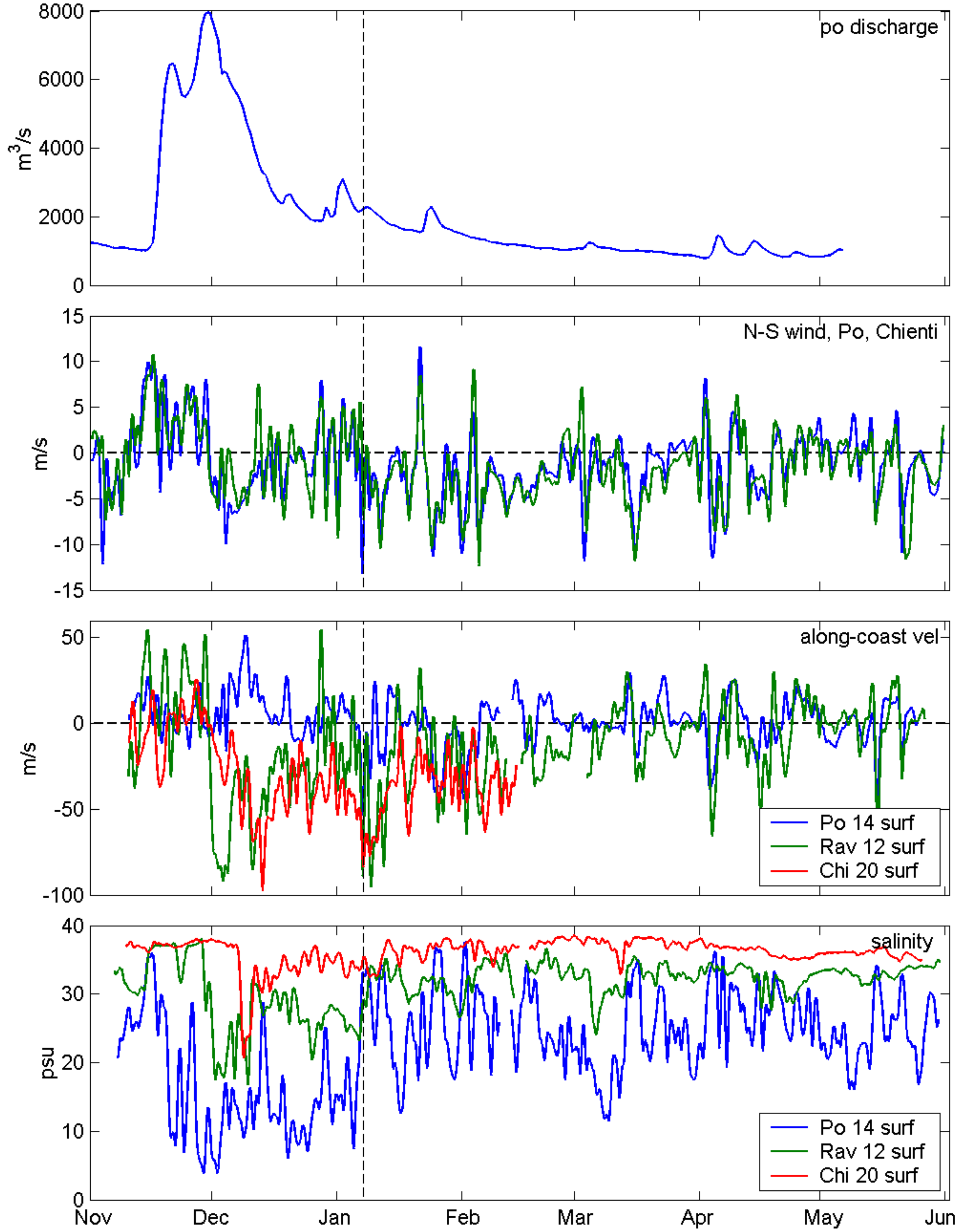

Fig. 2. Timeseries of forcing parameters, currents and water properties during the tripod-mooring deployment (November 2002 – June 2003). Wind data is from the LAMI model. Currents are near-surface observation from the tripod-mounted ADCPs. Salinities are from surface moorings (Rav:Ravenna, Chi:Chienti)

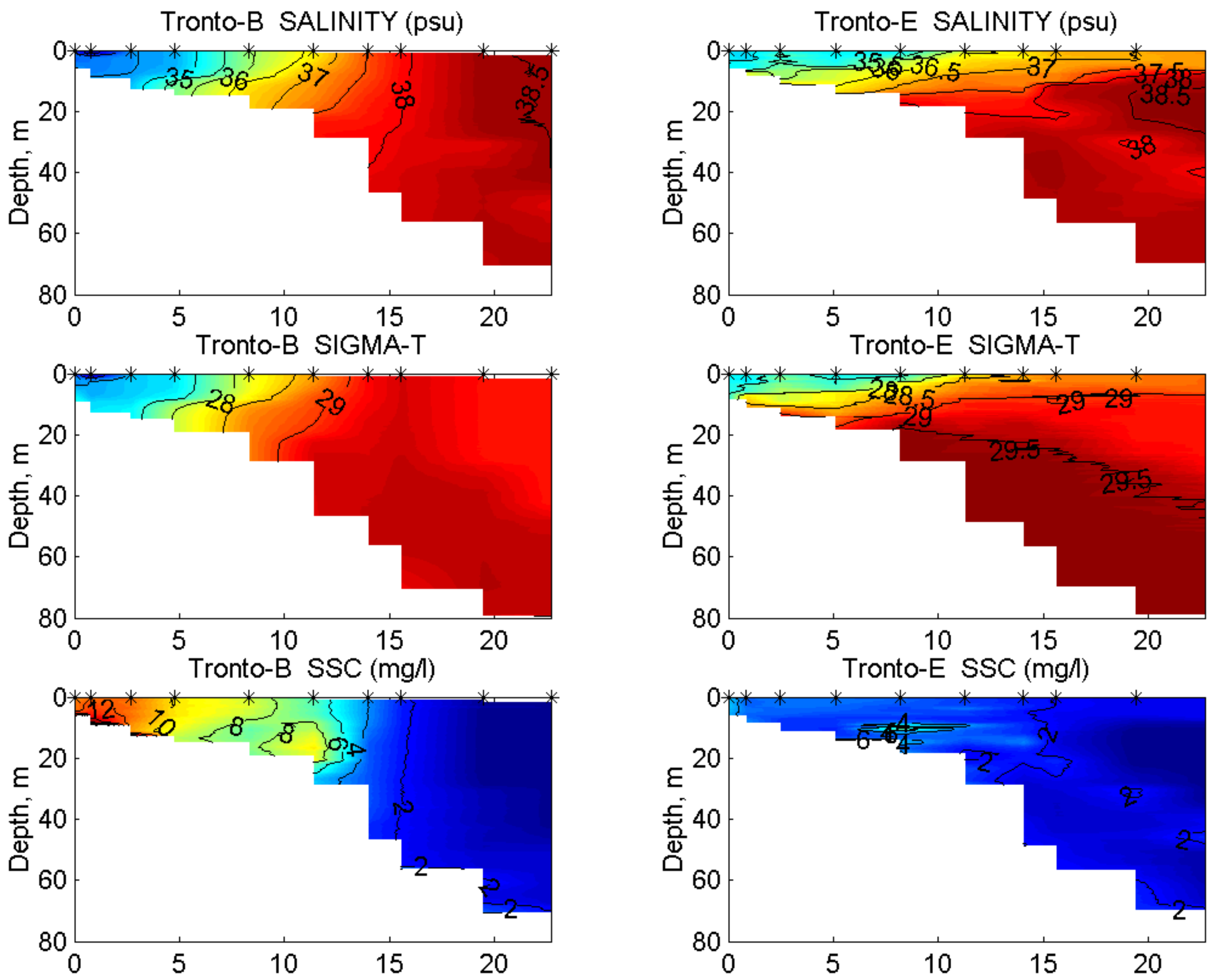

Figure. 3. Salinity, σ_t, and suspended sediment concentration (SSC) measurements from hydrographic surveys of the Tronto across-shelf transect (located at ~ 42°55'N; see Fig. 1). Data shown in the left panels were collected during a period of downwelling-favorable winds (2/19/03 22:30 – 2/20/03 1:50 GMT), whereas data shown in the right panels were collected during upwelling-favorable winds (2/27/03 10:30 – 14:35). Note the reduced stratification, deeper penetration of low salinity water, and increased SSC during the downwelling period.

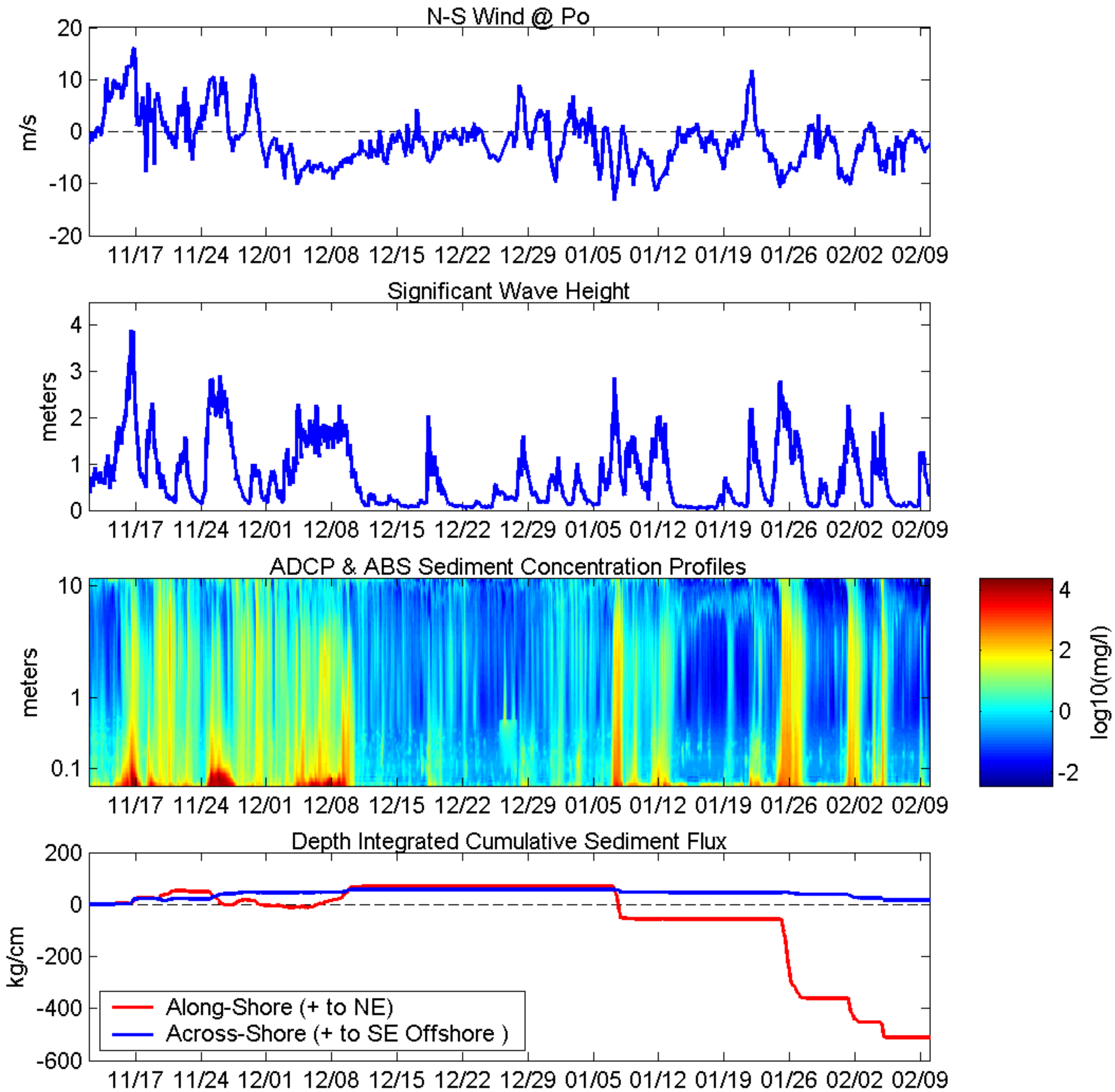

Figure 4: Wind, Wave Height, Sediment Concentration, and Cumulative sediment flux from the first half of the tripod deployment at the 12m Po site. Negative wind velocity indicates wind blowing toward the south. The sediment concentration profiles are estimated from the ADCP and ABS backscattered intensity with a preliminary calibration based on previous studies. The velocity for the flux estimate includes velocities from both the ADCP and 2 ADV sensors near the bed interpolated to form a surface to bed velocity profile. The dominant contribution of the along-shelf "Bora" events can be clearly seen in flux record.

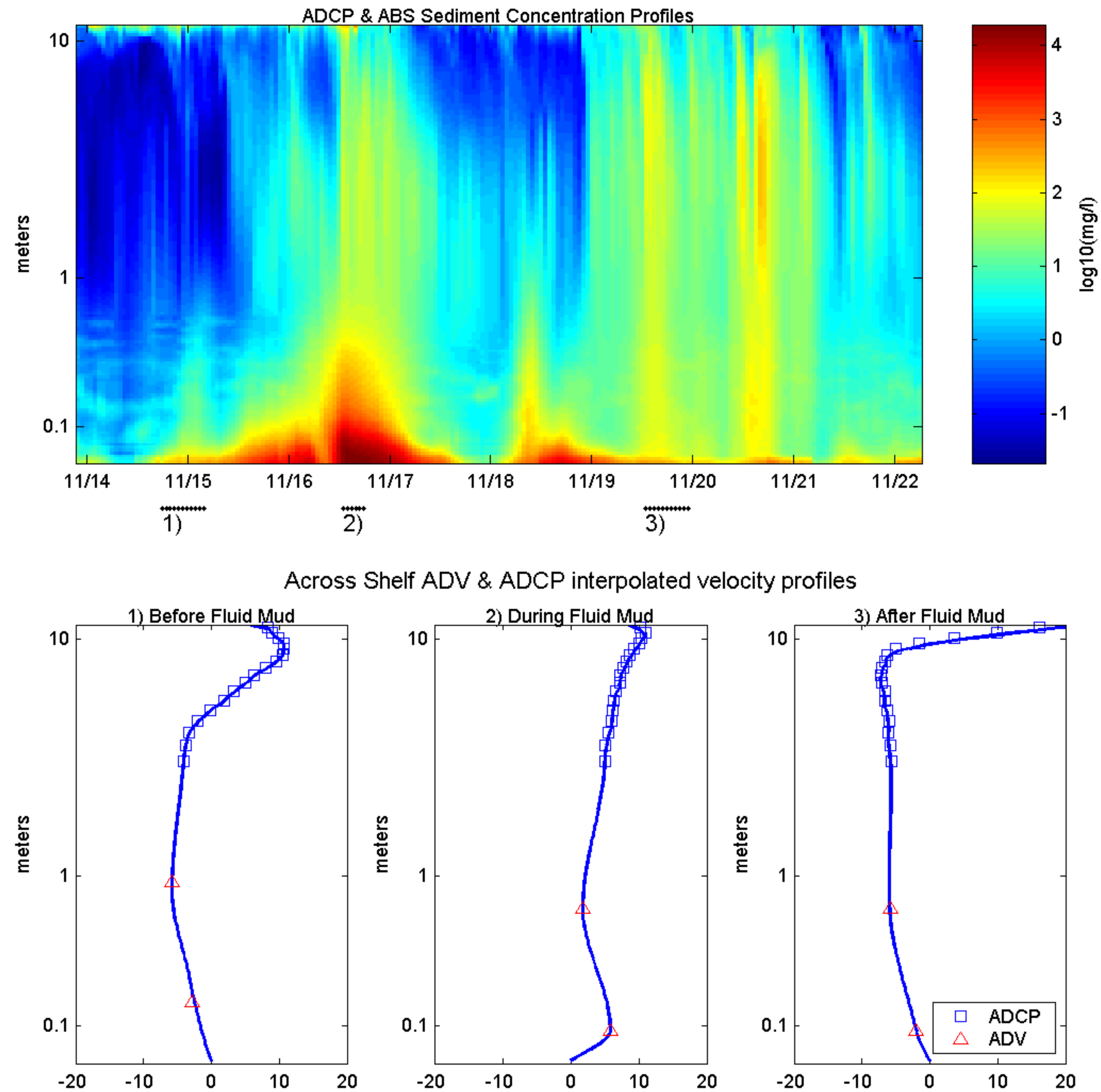

Figure 5: Top: ABS and ADCP calibrated sediment concentration profiles in mi d November showing a fluid mud layer on Nov 17th during the 3.7m wave event. The across-shelf velocity profile taken during the fluid mud event (averaged over the period labeled 2) shows the characteristic near-bed offshore flow associated with these gravitationally forced fluid mudflows. Profiles taken before and after (periods 1 and 3) the event show a more typical frictional boundary layer profile with velocities monotonically decreasing in the lower 1 m.